



7/11/11

# Educational Brief

## Exploring Mars

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**W**HY EXPLORE MARS? Why would we explore Mars, the fourth planet from the Sun, the next outward from Earth? What is there for humankind?

Through a telescope, Mars reveals few details: an orange, round world splashed with gray, with white poles, rarely obscured by clouds. Close up, Mars is stunning: clouds hovering above lava-draped volcanos, a canyon system that would stretch nearly across the United States, towering ice cliffs striped with red. Mars's past is laid bare in the landscape. Impact scars mark world-jarring collisions with asteroids, and deep winding channels recall titanic floods. But robot eyes alone have seen these sights.

Scientists believe that Mars is the only planet besides Earth that was ever cut by flowing water or graced by lakes and ponds. Now, that water is frozen at the poles and buried beneath Mars's frigid deserts. In those ancient Martian pools, might life have sprung up and prospered? The pools are dry and sterile today, but could life persist in deep and hidden places? Someday, will humans walk those distant deserts, seeking signs of ancient life?



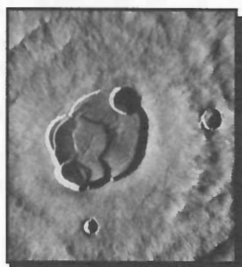
*This photo from the Hubble Space Telescope shows Mars as seen from Earth orbit. The north polar cap is at the top of the image. The storm system near the polar cap is 1,600 kilometers across.*

## A HISTORY OF EXPLORATION

**H**umans have known of Mars since before recorded history.

Even 3,600 years ago, the Babylonians wrote about Mars's looping motion across the sky and changing brightness. Mars was one of five "stars that wandered" among the fixed stars of the night and was special because of its red color. In ancient India, Mars appeared like a fire in the sky—for many other cultures, its redness recalled the fire and blood of war. In ancient Greece, the red wanderer personified the god of war, Ares. When the Romans conquered Greece, they adopted this symbolism and named the planet for their god of war, Mars.

Through the Middle Ages, astrologers studied Mars's motions to help them predict the future—they believed that if Mars moved unfavorably, wars would be lost! But no one could predict Mars's motion accurately, even using Copernicus's theory of 1543 stating that the planets orbit in perfect circles around the Sun. Johannes Kepler solved this puzzle in 1609 when he discovered that Mars orbits the Sun in an ellipse, not a



*The caldera at the summit of the Olympus Mons volcano is 90 kilometers across and about 3 kilometers deep.*

circle. Seventy-five years later, Kepler's solution was crucial to Isaac Newton's discovery of the law of gravity.

While Kepler explained its orbit, Galileo Galilei transformed Mars into a world. In 1609, Galileo first viewed Mars through his newly invented telescope. Although his telescope was no better than a modern toy, it revealed enough to prove that Mars was a large sphere, a world like the Earth. Could this new world be inhabited? As telescopes improved, more of Mars could be seen: polar icecaps, color patterns on its face, clouds, and hazes. These observations all fit a habitable planet, and speculations that Mars was inhabited became more and more believable.

The idea of living Martians came to full flower in 1877 when the Italian astronomer Giovanni Schiaparelli observed thin, dark lines crossing Mars's bright "continents." He called the lines "canali," "channels" in Italian, and the word was widely misread as "canals." In the U.S., Percival Lowell seized on the canals as proof of a Martian civilization advanced enough to move water across a whole world. Some scientists agreed, but most thought that the canals were optical illusions. They thought that Mars was too cold and its air too thin for life as we know it.

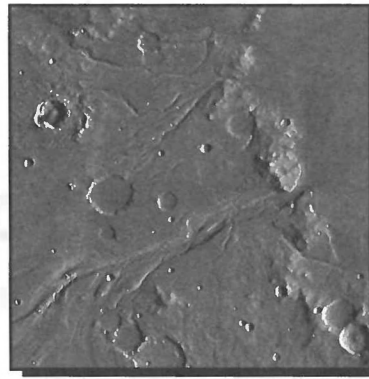
Understanding of Mars advanced little from Lowell's time in the late 19th century until 1965, when the Mariner 4 spacecraft

flew within 10,000 kilometers of the Martian surface. Its pictures, the first close-up views of Mars, showed a Moonlike landscape of plains pocked by impact craters. There were no canals or other signs of life. Mariner 4 finally proved that Mars's atmosphere, only 0.7 percent as thick as Earth's, was much too thin for life as we know it.

Four years later, the twin spacecraft Mariner 6 and Mariner 7 flew by Mars again, carrying cameras and spectrometers to measure the temperature of Mars's surface and the composition of its atmosphere. Their photos again showed no canals or other signs of life, but did reveal a volcano, plains without impact craters, and areas of chaotic hills. Mars's mass and density were calculated from spacecraft tracking. The spectrometers showed that Mars was very cold ( $-123^{\circ}\text{C}$  at the south pole), and that Mars's thin atmosphere was almost all carbon dioxide.

Exciting as they were, the early Mariners spent only a short time near Mars as they flew past; more time was needed, and that meant going into orbit. So in 1971, Mariner 9 arrived at Mars and became the first artificial object ever to orbit another planet. More than twice as big as its predecessors, Mariner 9 carried color cameras and new instruments tailored to investigating Mars's surface and atmosphere. An unsung part of the spacecraft was its computer system, which allowed Mariner 9 to wait until Mars's atmosphere cleared of a planetwide dust storm. Mariner 9 operated for almost a year, mapped 85 percent of Mars's surface in more than 7,000 images, analyzed Mars's gravity field, measured surface temperatures and dust abundances, and measured temperatures and humidity of its atmosphere.

Mariner 9's view of Mars was the first detailed global view of another planet; it revealed a "new Mars" unlike any earlier concept. The earlier Mariners had seen land typical of the southern hemisphere: craters and more craters. Mariner 9 saw things they had missed, such as the Valles Marineris, a canyon up to 100 kilometers wide and 10 kilometers deep that would reach



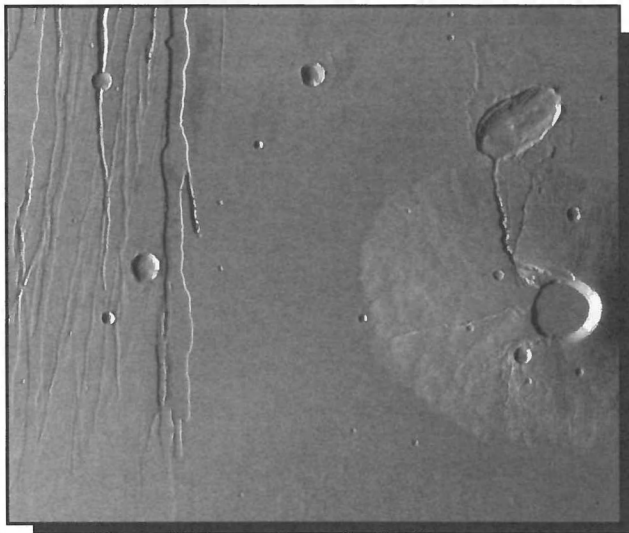
*These channels in Maja Valles were cut by giant floods at some point in the history of Mars. The scene is 225 kilometers across.*

from Los Angeles to New York! Giant valleys extend from the Valles and elsewhere and are mute testimony to devastating floods in Mars's distant past. Most of the valleys end in the northern plains, a vast lowland encompassing almost a third of the planet. There, the ancient floodwaters ponded into huge lakes or perhaps even an ocean. Signs of water appear in the southern highlands, too, for the most part as small valleys draining away from the largest craters and uplands. Despite these signs of ancient water, Mars now is too cold and its atmosphere too thin for liquid water to remain.

Mariner 9 also was the first to see Mars's volcanos, the biggest in the solar system. The biggest of all, Olympus Mons, is 600 kilometers across at its base and 21 kilometers tall. Smaller volcanos and lava flows appear all over Mars, especially on the Tharsis Rise, a huge bulge distorting Mars's spherical shape. Looking toward space, Mariner 9 took the first close-up images of Mars's moons, Phobos and Deimos. They are little more than large potato-shaped rocks, 10–20 kilometers long, and appear similar to asteroids.



*Mars's larger moon, Phobos. The crater on the near end is 10 kilometers in diameter.*



*Ceraunius Tholus volcano on the Tharsis Rise. The scene is 215 kilometers across.*

Mariner 9's global perspective and spectacular images of water-carved landscapes inspired further exploration of Mars to focus on the search for life. After extensive development, the twin spacecraft Viking 1 and 2 were launched in 1975 and entered Mars orbit in 1976. Each Viking was actually two spacecraft: an orbiter and a lander. Each orbiter had a pair of cameras and instruments for mapping surface temperature and atmosphere humidity. Each lander included a weather station, a seismometer for detecting "Marsquakes," instruments for analyzing soil, and a stereo TV camera.





*Dark rocks and white frost at the Viking 2 lander site. The largest rocks are about 1 meter long.*

olation of dark, rounded rocks and brick-red dust under a pink sky. The rocks were probably volcanic, pitted and smoothed by eons of blowing sands. On landing, the winds were light, at most 30 kilometers per hour. Viking 1 sat at a latitude comparable to the Sahara Desert on Earth, but its daytime temperatures climbed to a high of  $-10^{\circ}\text{C}$  and dropped to a numbing  $-90^{\circ}\text{C}$  before sunrise.

The Viking 2 lander touched down 2 months later on Utopia Planitia, closer to Mars's north pole, a latitude comparable to Maine or Mongolia on Earth. The plains of Utopia were rockier than the Viking 1 site in Chryse; one of Viking 2's legs stood on a rock. The landscape at Utopia was nearly flat; only a few low crater hills appeared on the distant horizon. In the summer, Utopia was no warmer than Chryse, but its winter night temperatures plunged to  $-120^{\circ}\text{C}$ . In winter, a thin layer of water frost was present for several months.

The Viking landers saw nothing alive and recorded no movement except blowing sand, shifting dunes, and their own robot arms. The arms pushed and scraped the Martian soil and scooped some for analysis. The landers' soil instruments were designed to detect Earthlike life. The instruments cooked soil, soaked it, and fed it nutrient broth. Although the soil contained no organic material, a few experiments seemed to indicate living organisms. After years of debate, almost all scientists now agree that the life signs came from unusual minerals in the soil and that Mars's surface is lifeless.

Meanwhile, the two Viking orbiters sailed overhead, recording the Martian landscape. Instruments measured water abundances in the atmosphere and temperatures on the surface, both during the day and at night. The orbiters took more than 52,000 images, giving complete coverage of Mars in great detail. These images have fueled years of intense study of Mars and are

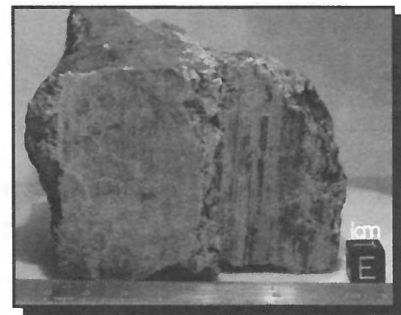
The Viking 1 lander touched down gently on July 20, 1976, on Chryse Planitia in the northern lowlands. Its robot eyes took the first photos of the Martian surface: a rolling des-

still yielding new insights into its volcanos, water, and ancient history.

From the end of the Viking program in 1982 until 1996, there were no successful spacecraft missions to Mars. Between 1988 and 1996, four spacecraft, one from the United States and three from Russia, were unsuccessful. Of these, only the Russian Phobos 2 spacecraft returned even a limited amount of useful data. These setbacks were unfortunate and showed that space exploration remained a difficult and challenging endeavor. Beginning in late 1996, however, the United States successfully resumed robotic exploration of Mars.

Without spacecraft at Mars, the Hubble Space Telescope was one of the few highlights of Mars exploration. Hubble cannot see surface details smaller than about 16 kilometers, but it can see Mars well enough to map clouds, dust storms, and seasonal changes in the polar caps. Measurements from Hubble show that Mars's atmosphere is now colder and much less dusty than it was during the Viking missions. Clouds of water ice are more abundant now than during the Viking missions and show how water moves from pole to pole as Mars's seasons change.

Another highlight in Mars exploration was the discovery that a few meteorites on Earth came originally from Mars. Twenty-four Martian meteorites are known as of 2001. These meteorites contain traces of gas identical to the Martian atmosphere as analyzed by the Viking landers. Asteroid impacts ejected the meteorites off Mars into orbit around the Sun; after millions of years, they landed on Earth. The Martian meteorites are all volcanic rocks; most are young (erupted only 180 million years ago); and almost all have reacted with Martian groundwater. These meteorites have revolutionized thinking about Mars's atmosphere and its water and are "ground truth" for interpreting images of the distant geology of Mars. The Martian meteorites are almost like sample return missions, except that we don't know where on Mars they formed. Some scientists believe that one Martian meteorite includes traces of ancient Martian life—fossilized Martian bacteria. However, many scientists remain unconvinced by this claim, which is now a topic of intense investigation.



## WHY CONTINUE?

Is there any reason to continue exploring Mars? Haven't we learned everything already? Telescope and spacecraft exploration have taught us a lot, but many important questions remain unanswered.

For instance, why is Mars's surface (with many craters and huge volcanos, and no continents) different from Earth's surface (with continents and chains of smaller volcanos, but few craters)?

The answer seems to lie deep within the planets, where hot rock flows slowly upward toward the surface. This motion is called mantle convection, and it seems to take different forms on Earth and Mars. On Earth, mantle convection moves large pieces of the surface, the geologic plates, and most volcanos, earthquakes, and mountains form at plate boundaries. On Mars, however, the upward flow of mantle rock bows up the surface but doesn't



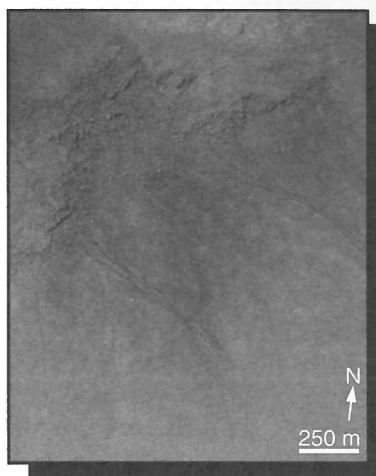


break it into pieces. The upward flow is centered at Tharsis, a bulge or high plateau about 4,000 kilometers across and up to 10 kilometers high. Tharsis is covered with volcanos that reach even higher; Olympus Mons is 21 kilometers tall. It appears that the volcanos on Tharsis have erupted for almost the entire history of Mars. The Tharsis volcanos might still be active, but dormant—no volcano eruptions have ever been seen. Around Tharsis are many long cracks (including the Valles Marineris), showing that the Martian crust was stretched and broken as Tharsis swelled. The high elevations, volcanos, and cracks were all caused by mantle convection. But compare this stable pattern with that of Earth, where mantle convection produces chains of volcanos and long mountain ranges that come and go through time.

Another question: Why doesn't Mars have oceans like Earth does? Mars's atmosphere is now too thin and its temperature too

cold to allow liquid water at the surface. But the important questions are about water itself; how much water does Mars have, and where is it? Mars certainly had surface water and groundwater once; scientists believe that only liquid water could have shaped the valley networks in the highlands and the huge flood channels that cut from the highlands to the northern lowlands. But how much water was there? Estimates range from the equivalent of an ocean 10 meters deep, covering the entire surface, to the equivalent of a layer kilometers deep. The first is not much water at all, and the second is a lot of water! However much water there was, it is not now on the surface, except for in the polar ice caps. Where did the water go? It could be underground in pools of groundwater, either small or huge depending on how much water Mars started with. Or it could have escaped to space and been lost completely; the hydrogen from water can escape easily through Mars's low gravity and small magnetic field.

And finally, we don't know if there is or was life on Mars. There are no canals or ancient cities, no clear signs of any life on Mars's inhospitable surface. But Mars's climate was mild once, with a thicker atmosphere, flowing water, open lakes, and perhaps even an ocean. Life on Earth may have started under similar conditions, possibly at underwater hot springs. With its volcanos and lava flows, Mars probably also had hot springs. If Mars had oceans or lakes, could life have also started on Mars? We know about the origins and history of life on Earth from fossils—how and where would we look for fossils on Mars? And why confine our search to Mars's surface? On Earth, many kinds of bacteria live deep inside rocks and die when exposed to light and fresh air. Could organisms like these be alive and prospering in groundwater far beneath the surface of Mars? Do we now have fossils of these bacteria, preserved for eons in the Martian meteorites?

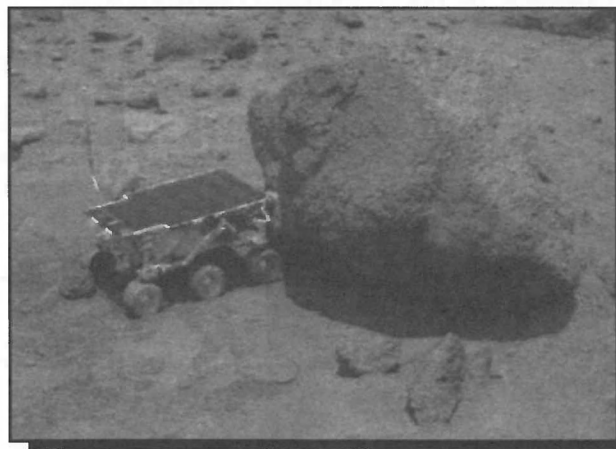


*This image shows gullies on the pit walls. Scientists think that the gullies are formed by material flowing down hill, such as water, liquid carbon dioxide, or dust avalanches. The dark floors must be young, or else they would be covered by light-colored dust.*

## EXPLORATION NOW

The United States has resumed an active program of robotic spacecraft exploration of Mars. These spacecraft may provide answers for some of these important questions during the next several years.

Mars Pathfinder, the first successful space probe to Mars in 20 years, landed on July 4, 1997, near the mouth of Ares Vallis. Viewed from orbit, Ares Vallis looks like a giant flood channel that formed long ago. Photographs taken by Pathfinder reinforce this view, showing an undulating landscape with many rocks, some lined up in the direction that the flood waters flowed. Pathfinder carried a miniature, six-wheeled rover called Sojourner that explored the region around the lander. Chemical measurements made by Sojourner suggest that the rocks in this region are basalts or basaltic-andesites, types of volcanic rock that are common on Earth (for example, the Hawaiian volcanos are made of basalt). During its 3 months of activity, Pathfinder also measured temperatures and wind speeds on Mars and even



*The Sojourner rover measures the composition of the boulder Yogi, which is about 2 meters across.*



recorded the passing of several “dust devils” (swirling dust clouds) over the landing site. Radio tracking of Pathfinder provided new information about the rotation of Mars, particularly about how it slowly “wobbles.” All planets wobble slightly as they rotate (like a top), and the degree of this wobbling depends on how material is distributed inside the planet. The data for Mars indicate that its central core is composed mainly of iron and fills about half the planet.

Mars Global Surveyor entered orbit around Mars in September 1997. A camera is obtaining images that show features as small as 2 meters in size, 10 to 100 times as detailed as previous images of Mars. These images show numerous sand dunes, layered rocks that could have been deposited by water or wind, gullies that might have been caused by recent liquid water, and lava flows that may be only 10 million years old. An altimeter uses a laser beam to measure the topography of Mars, such as the heights of its volcanos and the depths of its canyons and craters. The altimeter has shown that the northern plains of Mars are remarkably smooth. Some scientists believe that this part of Mars was once covered by an ocean and that sediments deposited on

the ocean floor formed the smooth terrain. Other scientists disagree, saying that the detailed images do not show features similar to those seen at ocean shorelines on Earth. Mars does not have north and south magnetic poles like Earth, but some surprising magnetic stripes have been found on Mars. These stripes are thought to be about 4 billion years old and indicate that ancient Mars had a strong magnetic field that later disappeared. Several of these instruments are also measuring weather on Mars, such as temperatures, cloud heights, and seasonal changes in the polar caps. Detailed measurements were made of the dust storm that covered most of Mars during the summer of 2001.

Mars Odyssey entered orbit around Mars in October 2001. Its instruments will measure the composition of the rocks and soil and the radiation environment of Mars. Measurements of gamma rays and neutrons have already been used to map the distribution of water and ice near the surface of Mars. The gamma-ray measurements will also be used to map the distribution of other elements in Martian rocks such as iron, silicon, and aluminum. The thermal infrared imaging system is revealing new details

about the geology of the Martian surface. It is also looking for minerals such as clay and carbonates, which may provide clues to the early climate of Mars. The results of these two experiments may also assist in the selection of landing sites for future robotic rovers. A third experiment is measuring space radiation that might be hazardous to future human explorers. Odyssey’s mission is planned to continue until the middle of 2004.

As Earth and Mars orbit the Sun, the opportunities for the easiest trips from one planet to the other occur about every 26 months. In 2003, NASA plans to launch two spacecraft that will land on Mars and deploy two robotic rovers. These rovers will travel up to a kilometer from the landing site, taking close-up photos of the Martian surface and making detailed chemical measurements of the rocks and soil. In 2005, an orbiter mission will take extremely detailed images of Mars, showing features as small as 30 centimeters across. This mission will also include a radar instrument that will probe beneath the surface of Mars to look for evidence of underground water and ice.

Other countries are also exploring Mars. The European Space Agency’s Mars Express mission will be launched in 2003. It will study the geology of Mars from orbit and will also include a small lander, Beagle 2. Japan’s Nozomi

#### U.S. MARS MISSIONS—SUCCESSFUL AND ONGOING

MISSION	LAUNCH	ARRIVAL	HIGHLIGHTS
Mariner 4 Flyby	Nov. 28, 1964	July 14, 1965	22 black and white images of desolate, cratered southern hemisphere. No canals or signs of life. Water frost seen. Proof that Mars’s atmosphere is very thin.
Mariner 6 and 7 Flybys	Feb. 24 and Mar. 27, 1969	July 31 and Aug. 5, 1969	75 and 126 black-and-white images of equatorial region, southern hemisphere, and south polar ice. Measured Mars’s mass and density.
Mariner 9 Orbiter	May 30, 1971	Orbit: Nov. 14, 1971	7,329 images, many in color. First views of huge volcanos of Tharsis, chasms of Valles Marineris, water-cut channels, Mars’s moons.
Viking 1 Orbiter, Lander	Aug. 20, 1975  1976	Orbit: June 19, 1976 Landing: July 20,	Orbiter takes >30,000 images of surface, many in color. Global maps of temperature, atmosphere water content, surface properties. Lander gives first images from Mars’s surface: dark rocks, red dust, pink sky. Tests soil for life and finds none. Records Mars’s weather.
Viking 2 Orbiter, Lander	Sept. 9, 1975	Orbit: Aug. 7, 1976 Landing: Sept. 3, 1976	Like Viking 1, Orbiter takes >20,000 images of surface. Lander finds no life; again dark rocks, red dust, pink sky. Records Mars’s weather.
Mars Global Surveyor	Nov. 7, 1996	Orbit: Sept. 11, 1997	High-resolution images, maps of surface elevation and mineral distribution.
Mars Pathfinder Lander	Dec. 4, 1996	Landing: July 4, 1997	Landing in Ares Vallis; rover tests, imaging, and chemical investigations.
Mars Odyssey	April 7, 2001	Orbit: Oct. 23, 2001	Global measurements of rock soil compositions and radiation.

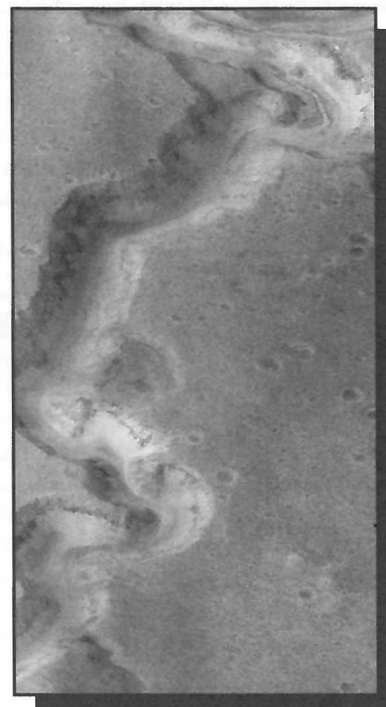
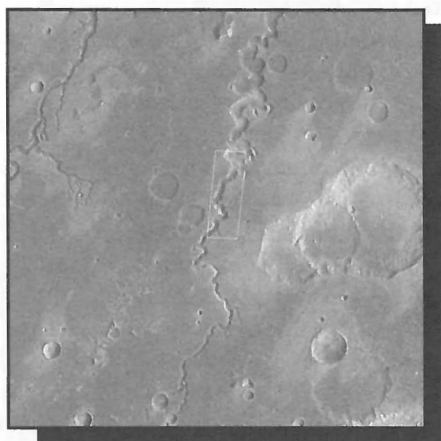


spacecraft is already en route to Mars. When it arrives in December 2003, it will study the upper atmosphere of Mars and its interaction with the solar wind.

Further in the future, more sophisticated rovers may travel longer distances across the surface. Large landers might drill below the surface of Mars and look for evidence of layering in the subsurface rocks. Such layering would provide information about the geologic history of Mars and clues about how the climate of Mars has changed over time. A lander network of seismometers to measure “Marsquakes” could provide information about the internal structure of Mars. Meteorological instruments on these landers could add to our understanding of weather

on Mars. Some of these missions may involve collaborations between NASA and various international partners. Studying Mars rocks in Earth laboratories will provide a far more detailed understanding of Mars than it is possible to obtain from unpiloted spacecraft alone. Designing a rocket that is able to return such samples to Earth remains an important engineering challenge. A sample return mission is unlikely to be attempted before 2014.

When will humans explore Mars? No space agency has concrete plans for human landings on Mars in the near future; landings before 2020 are unlikely. But someday, people will descend from a spacecraft, stand on red soil, and see for themselves the canyons, volcanos, and dried lakebeds of Mars.



(Left) A Viking 1 orbiter view of Nanedi Valles. The many impact craters indicate that this is an old area of Mars. The scene is about 100 kilometers across, and the white box outlines the region in the close-up image. (Right) This Mars Global Surveyor image shows details in part of Nanedi Valles, which was formed by a combination of flowing groundwater and collapse of the channel walls. The scene is 10 kilometers across. This image has 15 times as much detail as the Viking image.

## FOR THE CLASSROOM

### Activity 1: Geography and Mission Planning

These locations have been considered as possible landing sites for NASA missions to Mars.

1a. If Martians sent spacecraft to these same latitudes and longitudes on Earth, what would they find? Would they find life or an advanced civilization?

1b. If you were a Martian, why would you explore Earth? Does Earth have resources you might need? What would you want to know about Earth? Where would you land first? (From B.M. French, *The Viking Discoveries*, NASA EP-146, Oct. 1977)

Latitude		Longitude	
1. 22° N	48° W		Viking 1 Site
2. 20° N	252° W		
3. 44° N	10° W		
4. 7° S	43° W		
5. 48° N	226° W		Viking 2 Site
6. 44° N	110° W		
7. 5° S	5° W		
8. 19° N	34° W		Mars Pathfinder Site
9. 76° S	195° W		
10. 2° S	6° W		Mars Exploration Rover
11. 15° S	185° W		Mars Exploration Rover
12. 10° N	270° W		Beagle 2



## Activity 2: Old, Relatively

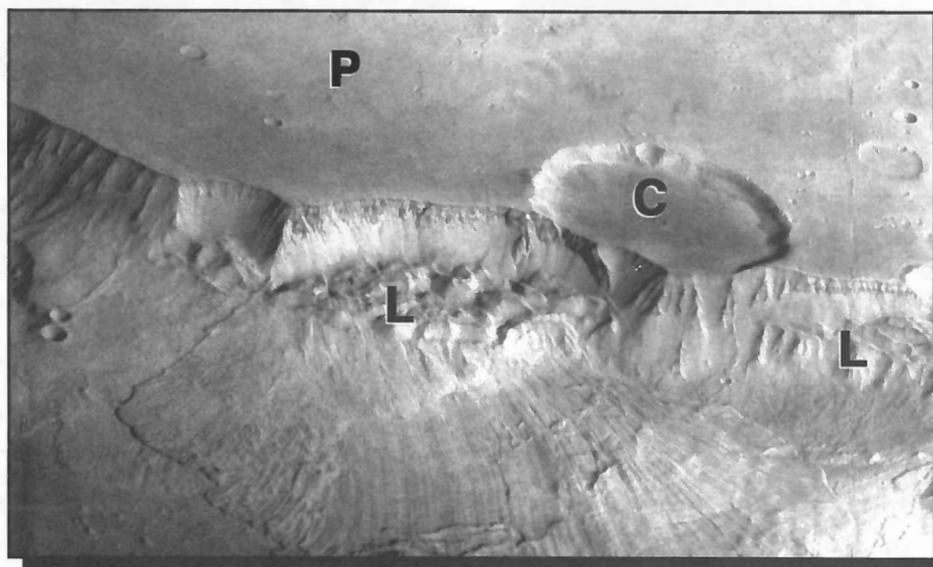
For exploring Mars, it is important to know which events happened in which order and which areas are older than others. A simple way of figuring out the sequence of events is **superposition**—most of the time, younger things are on top of older things, and younger (more recent) events affect older things.

2a. *Superposition in your life.* Is there a pile of stuff on your desk? On your teacher's? On a table or the floor at home? Where in the pile is the thing you used most recently? The thing next most recently? Where in the pile would you look for something you put down 10 minutes ago? When was the last time you (your teacher or your parent) used the things at the bottom of the pile?

2b. *Superposition on Mars.* Using superposition, we can sort out many of the complicated events in the history of Mars. For example, you can sort out all the events that affected the area of figure 1, which shows a small part of the wall of the great canyon system of Valles Marineris. Toward the top of the picture is a high plateau (labeled "P" on the picture), with a large, circular impact crater ("C"). It formed when a huge meteorite hit Mars's surface.

Below the plateau is the wall of Valles Marineris. Here, the wall has been cut away by huge landslides ("L"), which leave bumpy, rough land at the base of the wall and a thin, broad fan of dirt spreading out into the canyon floor. In the canyon wall, almost at its top, alternating layers of light and dark rock are exposed.

To discover the history of this part of the Valles Marineris, start by listing all the landscape features you can see and the events that caused them (don't bother listing every small crater by itself). Now list the events in order from oldest to youngest. (Hints: How many separate landslides are there? Is the large crater ("C") younger than the landslides? Are the landslides younger than the rock layers at the top of the walls? Are the small craters older or younger than the landslides?) Sometimes you cannot tell which of two events was younger. What additional information would help you tell? To learn more about this image, visit the Internet site <http://www.lpi.usra.edu/education/K12/gangis/mars.html>



**FIGURE 1.** Craters and landslides at the wall of Valles Marineris. Viewed at an angle, scene is 60 kilometers across.

## Activity 3: Impact Craters, More or Less

When large meteorites strike a planet's surface, they leave impact craters. Meteor Crater in Arizona is the most famous of the 150 impact craters known on Earth. During a meteorite impact, rocks from deep in a planet are gouged up and thrown onto the surface, so impact craters can be used like a mine or drill hole to show us rocks from underground. Also, the abundance of impact craters on a surface shows its age—the more craters on a surface, the older it must be.

3a. *Crater excavations: laboratory experiment.* Start with a flat sand surface: a playground sandbox is ideal, but any unbreak-

able box with a surface bigger than about 60 cm by 60 cm will do. Smooth the sand's surface and cover the sand with a layer of fine, contrasting powder: different sand, tempera paint powder, or colored sugar, for example. Cover this layer with a few millimeters of sand. Simulate the formation of an impact crater by throwing marbles or gravel into the sand. How deep is your crater? Does it excavate into the contrasting layer? How far was the contrasting powder thrown by the impact? This experiment can be expanded and quantified by experiments with different types of sand, different depths of burial, marbles of different sizes



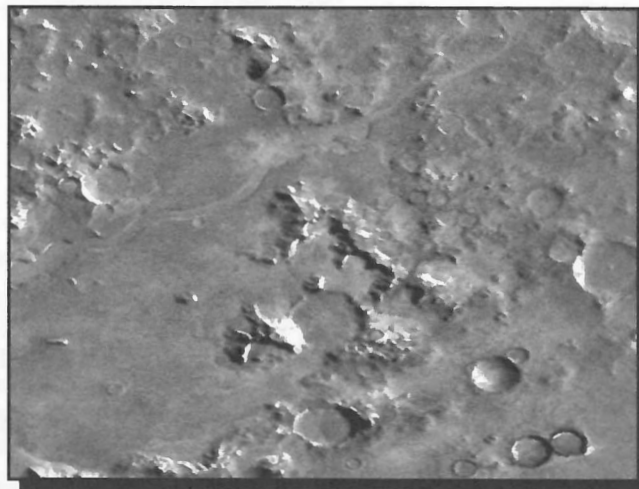
and weights, and different angles of impact. Using a slingshot to shoot the marbles will permit harder impacts and bigger craters, but careful supervision is required. **Be sure to wear eye protection.**

3b. *Craters old and new: laboratory experiment.* Make many craters on a smoothed sand surface by throwing gravel or marbles until the sand is evenly peppered with craters. Then smooth out half the sand surface, erasing all its craters. Resume throwing gravel or marbles at the sand, but only throw about half as many as before. Now, half the sand surface should be heavily cratered and the other half moderately cratered. If you hadn't seen it happen, could you tell which part of the sandbox was smoothed during the experiment?

3c. *Resurfacing—some thought questions.* Many processes on planets can erase, or smooth out, earlier landscapes. The word for this is resurfacing, literally putting a new surface on the land. What processes on Earth act to resurface its land? Compare figure 2 with a map or aerial photo of a place you know. Why does Mars have more craters than your place? Find a globe or map of the Moon. What resurfacing processes act on the Moon? Can impacts resurface a landscape?

3d. *The sandbox of Mars.* Figure 2 shows an area in Mars's southern hemisphere. On the figure or a photocopy, sketch or trace out all the circular rim craters you find (also outline incomplete circles). Then, draw a boundary line that separates areas with many craters from areas with few or no craters. Which of the two areas is younger? Remember that liquid water cannot

exist on Mars's surface now—what processes that don't require water could have resurfaced Mars? Look at the long, twisting feature that goes from the upper right corner to the middle of the left side of figure 2. Does anything on your State map have the same kind of swerving path? The feature might be a river bed, now bone-dry, of course. What was Mars's climate like when water flowed in that river? What happened to the water that once flowed in the river bed? Where is it now?



**FIGURE 2.** Ancient cratered highlands of Mars, east of the Hellas Basin. Scene is about 300 km across.

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Additional classroom mapping activities involving the Martian flood channels and Valles Marineris may be found at  
<http://www.lpi.usra.edu/expmars/activities.html>

Updates to this document and many additional images may be found at  
<http://www.lpi.usra.edu/expmars/expmars.html>

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## For More Information

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